AN OVERVIEW - NASA LERC STRUCTURES PROGRAM

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AN OVERVIEW –

NASA LERC STRUCTURES PROGRAMS

by

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LERC STRUCTURES AND ACOUSTICS DIVISION CAPABILITY

The Structures and Acoustics Division of the NASA Lewis Research Center has its genesis dating back to 1943. It has been an independent Division at Lewis since 1979. Its two primary capabilities are performance and life analysis of static and dynamic systems such as those found in aircraft and spacecraft propulsion systems and experiment al verification of these analyses. Research is conducted in-house, through university grants and contracts, and through cooperative programs with industry. Our work directly supports NASA's Advanced Subsonic Technology (AST), Smart Green Engine, Fast Quiet Engine, High-Temperatu re Materials and Processing (HiTEMP), Hybrid Hyperspeed Propulsion, Rotorcraft, High-Spe ed Research (HSR), and Aviation Safety Program (AvSP).

LeRC Structures & Acoustics Division
Two Primary Capabilities

- Analysis capability
- Experimental capability

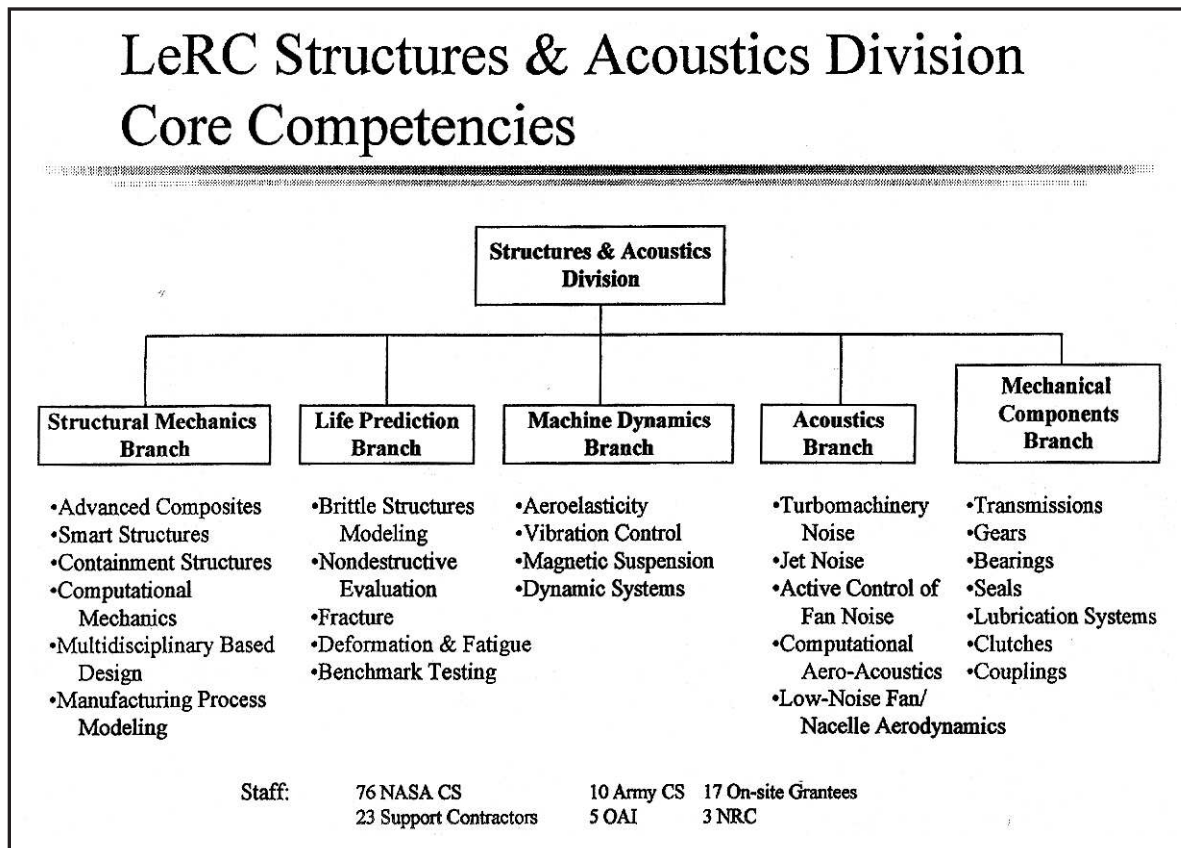**LERC STRUCTURES AND ACOUSTICS DIVISION CORE COMPETENCIES**

There are eight core competencies of the Structures and Acoustics Division. These are listed below. A primary focus of the Division has been the design a pplication of new composite materials into advanced aerospace structures. In addition, research is being performed on drive systems for helicopters and turboprop aircraft. Work is performed on aeroelasticity and aircraft engine noise suppression. Current goals emphasize lighterweight, more reliable aeropropulsion structures operating at higher temperatures.

LeRC Structures & Acoustics Division Core Competencies

- Computational tools
- Experimental methods and test techniques
- Structural concepts
- Advanced materials applications
- Mechanical drive systems
- Vibration control
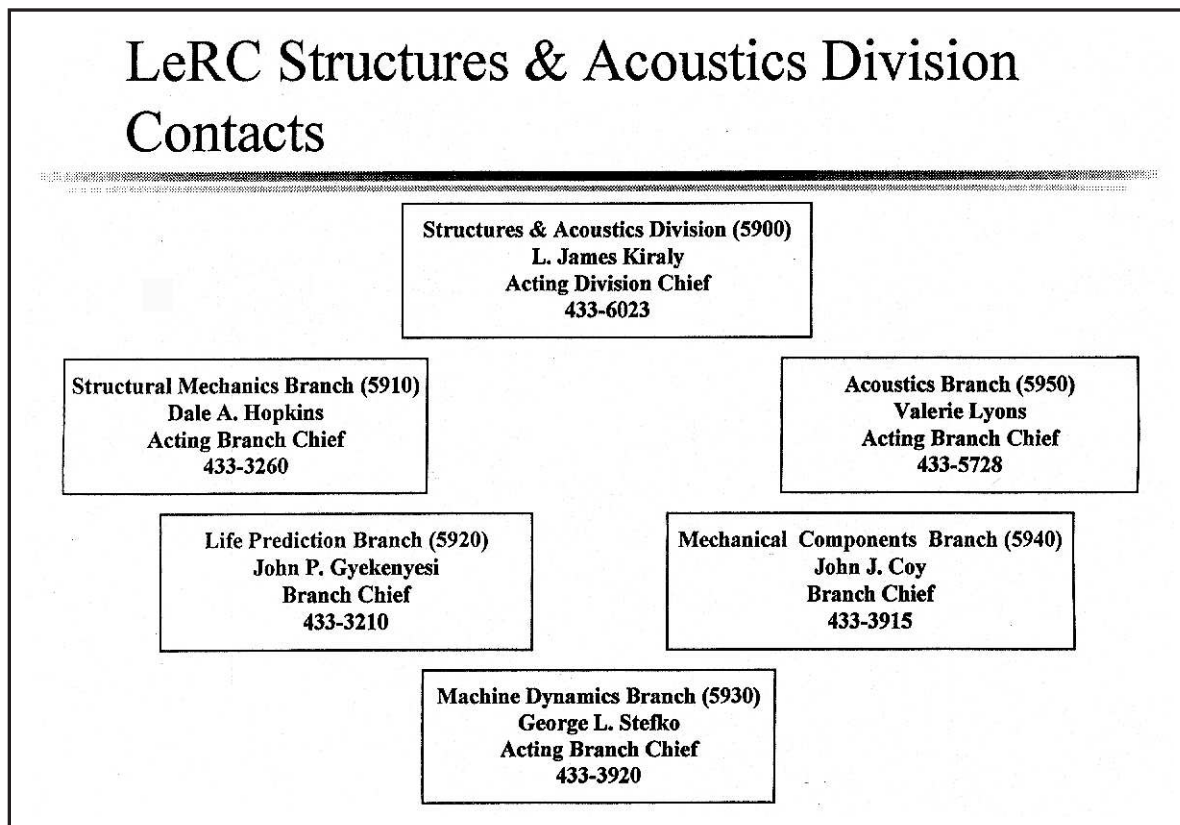- Aeroelastic codes
- Noise Suppression

LERC STRUCTURES AND ACOUSTICS DIVISION ORGANIZATION

    The Structures and Acoustics Division comprises five branches consisting of 134 engineers, scientists and support personnel. The staff consists of NASA Lewis civil servants and personnel from universities and private support organizations which ar e listed. The breakdown of the Division programs are shown under their respective branches.

LeRC Structures & Acoustics Division Core Competencies

Structures & Acoustics Division

Structural Mechanics Branch	Life Prediction Branch	Machine Dynamics Branch	Acoustics Branch	Mechanical Components Branch
•Advanced Composites •Smart Structures •Containment Structures •Computational Mechanics •Multidisciplinary Based Design •Manufacturing Process Modeling	•Brittle Structures Modeling •Nondestructive Evaluation •Fracture •Deformation & Fatigue •Benchmark Testing	•Aeroelasticity •Vibration Control •Magnetic Suspension •Dynamic Systems	•Turbomachinery Noise •Jet Noise •Active Control of Fan Noise •Computational Aero-Acoustics •Low-Noise Fan/ Nacelle Aerodynamics	•Transmissions •Gears •Bearings •Seals •Lubrication Systems •Clutches •Couplings

Staff: 76 NASA CS   10 Army CS   17 On-site Grantees
   23 Support Contractors   5 OAI   3 NRC

LERC STRUCTURES AND ACOUSTICS DIVISION CONTACTS

    The Structures and Acoustics Division welcomes inquirie s from industry, universities and other government organizations as well as private individual s. There exists many collaborative research and technology projects between outside organizatio ns and the various branches. Contacts for each of the organizational entities are shown.

LeRC Structures & Acoustics Division Contacts

Structures & Acoustics Division (5900)
L. James Kiraly
Acting Division Chief
433-6023

Structural Mechanics Branch (5910)
Dale A. Hopkins
Acting Branch Chief
433-3260

Acoustics Branch (5950)
Valerie Lyons
Acting Branch Chief
433-5728

Life Prediction Branch (5920)
John P. Gyekenyesi
Branch Chief
433-3210

Mechanical Components Branch (5940)
John J. Coy
Branch Chief
433-3915

Machine Dynamics Branch (5930)
George L. Stefko
Acting Branch Chief
433-3920

TEST AND EVALUATION

Unique mechanical testing and nondestructive evaluation techniques are being developed to make global civil aviation and access to space more competitive and affordable. A state-of-the-art computed tomography facility was developed to characterize critical manufacturing problems in advanced composite materials and engine subscale components. This facility provides rapid re-engineering and reduction in product development cycle time. A world-class benchmark testing facility for high temperature structures was established. This facility is used to verify and validate structural analyses methods for aeropropulsion systems operating at 1500 °C and to produce reliable test data for advanced materials in scale-up form subjected to prototypical operating conditions. The ballistic impact facility was built for testing light weight fan containment systems and other jet engine systems where impact strength is of concern. High temperature compliant engine seals are being developed to survive temperatures up to 1100°C, to have low leakage, to exhibit resilience with cycling, and to resist scrubbing damage.


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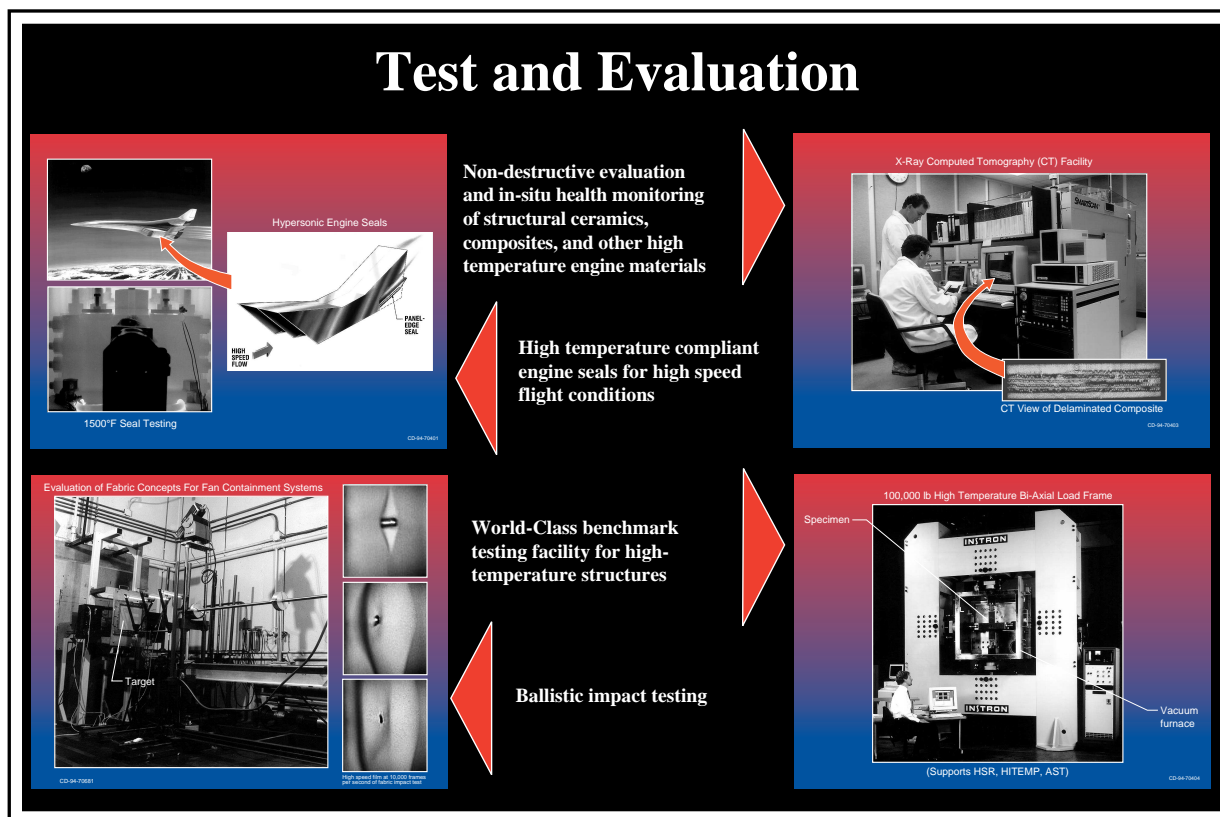
HIGH TEMPERATURE SEALING

The National Aerospace Plane Project identified a critical need for seals that could operate at or above 2000 °F. This temperature was in excess of conventional graphite a nd metal seal temperatures. A need existed for a seal that exhibits low leakage to limit parasitic losses; remains flexible at temperature; resists hydrogen embrittlement and oxidation; and be fabricable using available materials. In order to accommodate these requirements, research and development of braided seals made from high-temperature ceramics and super alloy fibers into leak resistant, abrasion resistant structures are being performed. This seal follows and seals significant engine sidewall distortions. This NASA potential seal concept was awarded the NASA 1997 Invention of the Year Award.

Hypersonic Engine Seals

PANEL-EDGE SEAL

HIGH SPEED FLOW

1500°F Seal Testing

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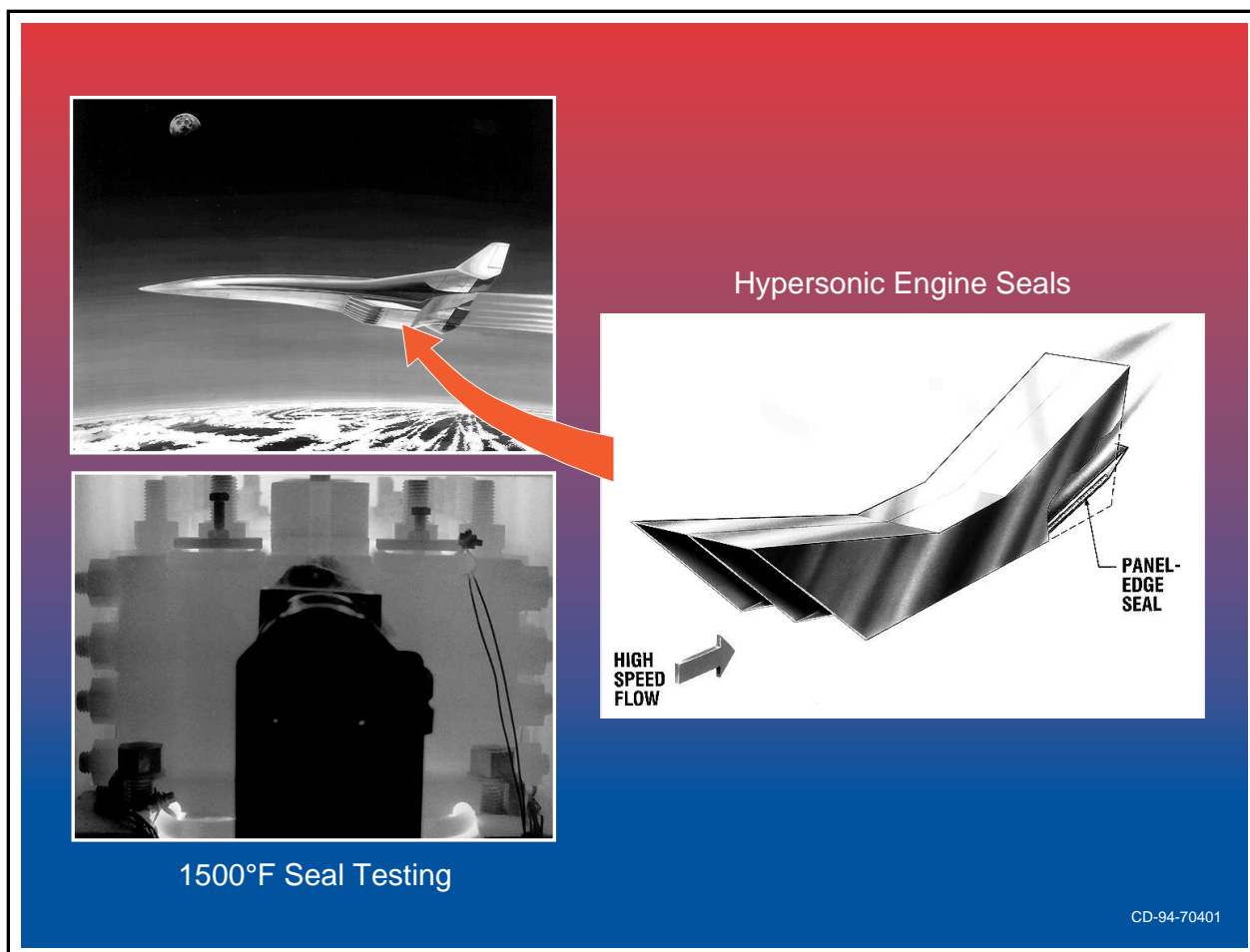
X-RAY COMPUTED TOMOGRAPHY

A state-of-the-art computed microtomography facility was established. This facility is used to characterize critical manufacturing problems in advanced com posite materials and engine subscale components as well as to provide rapid re-engineeri ng and reduction in product development cycle time. This facility is a modularized digital x-ray system that produces digital radiographic, tomographic and laminographic images. It is un ique for quality assurance of composites because it resolves volumetric flaws as small as $25 \times 25 \times 25$ mm (1 mill) in a cross section of up to 5×5 cm (2 in).

X-Ray Computed Tomography (CT) Facility
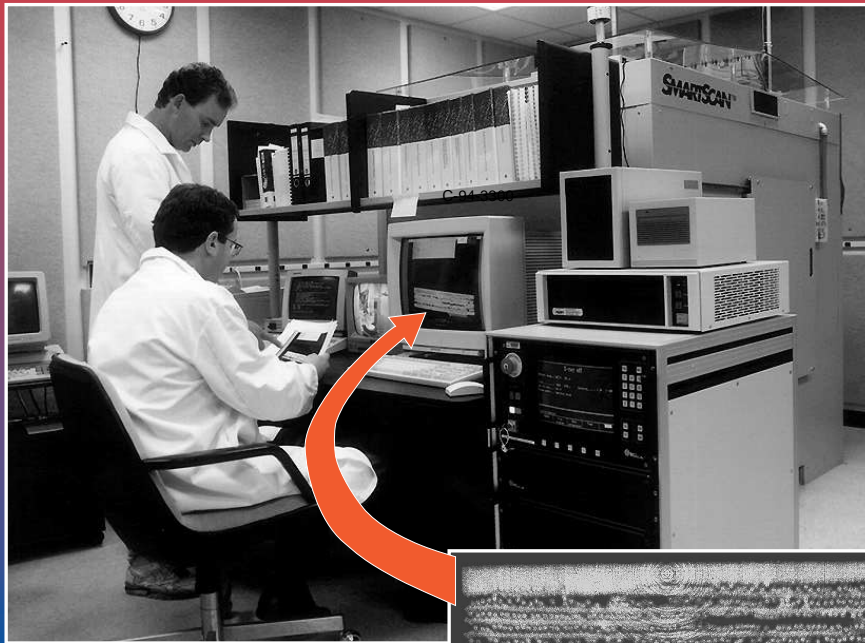
CT View of Delaminated Composite

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STRUCTURAL TESTING

A difficulty with most advanced materials is that the b ehavior of those materials at the test coupon level can be significantly different from that at the full-scale component level. A benchmark structural test facility has been developed to add ress scale-up issues by testing materials at the sub-element level. This facility can be use d to verify and validate structural analysis methods. Experimental conditions are generated under prototypical loading conditions including complex stress states. The experimental results are co mpared to those analytically predicted.

100,000 lb High Temperature Bi-Axial Load Frame

Specimen

Vacuum furnace

(Supports HSR, HITEMP, AST)

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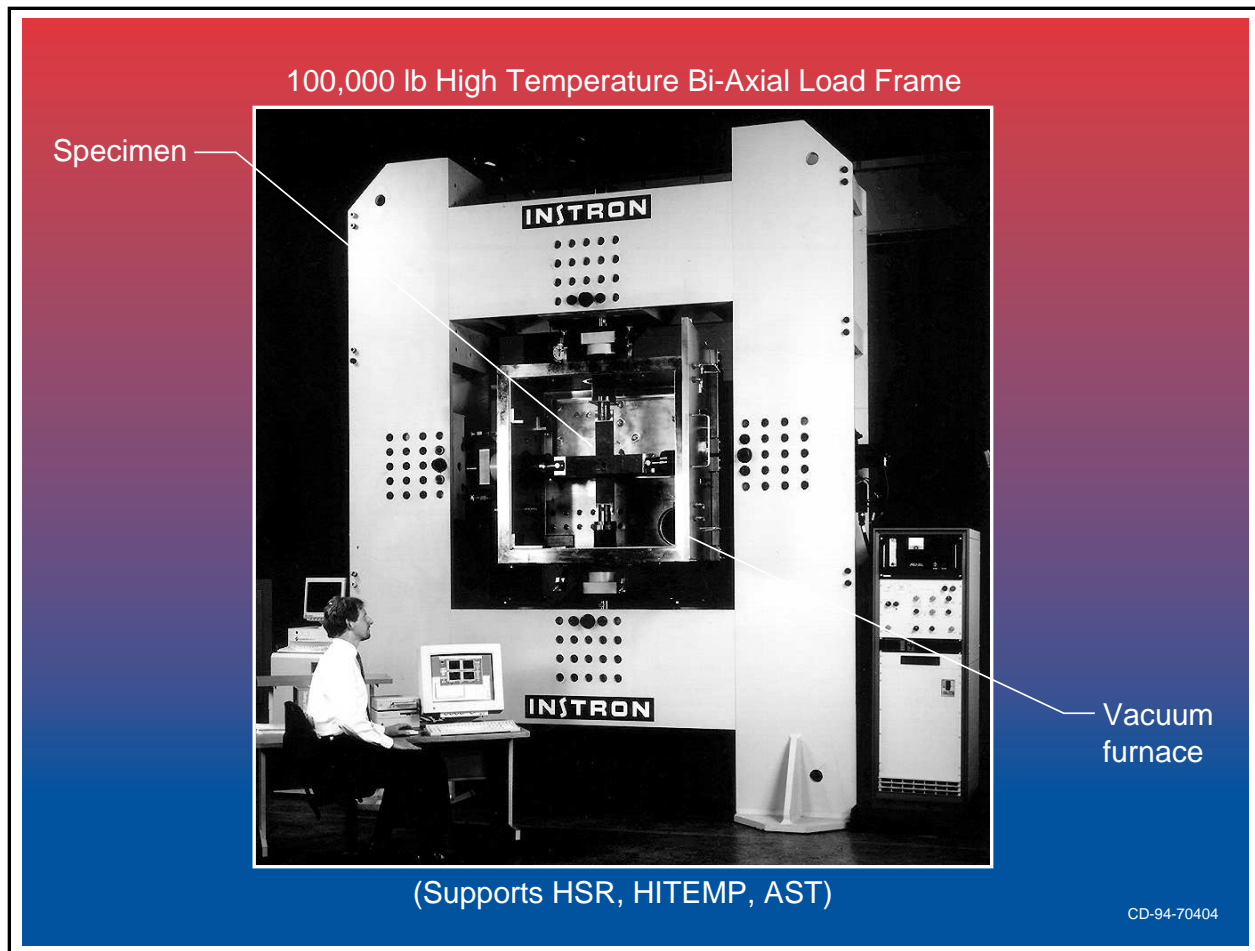
BALLISTIC IMPACT RESEARCH

Impact research is being conducted to reduce the weight of jet engine fan containment systems for future aircraft, assess the impact resistance of new turbine blade materials, and improve the ability of the material models in DYNA-3D to predict damage and failure. The work is both experimental and computational in nature. The ballistic impact laboratory currently has several gas guns ranging in size from 1/16" to eight inches in diameter. Projectiles weighing up to five pounds at velocities up to 1200 ft/sec. can be shot from these guns. Gun barrels range in size from 0.15 cm to 20 cm in diameter and can shoot project iles weighing up to 2.5 Kg at speeds of 350 m/sec. A computational capability exists complementing the experimental effort. The LS-DYNA-3D explicit finite element analysis code is used to predict deformation and damage of the impact events.

Evaluation of Fabric Concepts For Fan Containment Systems

Target
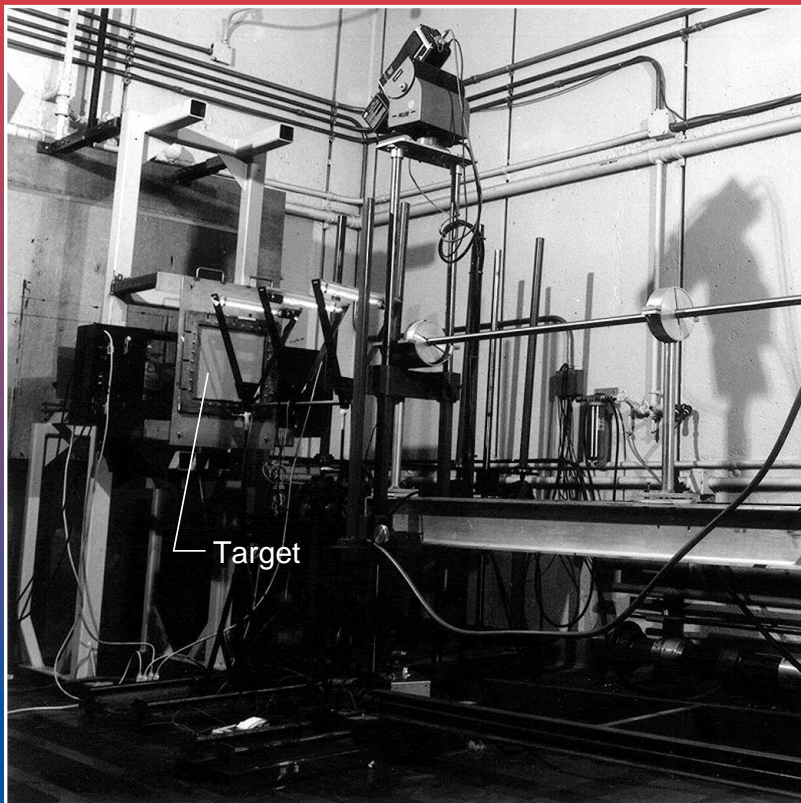
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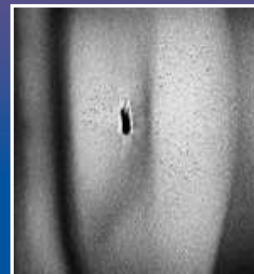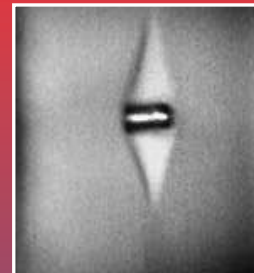
High speed film at 10,000 frames per second of fabric impact test

MACHINERY DYNAMICS

Our machinery dynamics research can be broadly classifi ed into four major activities: turbomachinery aeroelasticity, vibration control, dynamic systems response and analysis, and computational structural methods. This work is applicable to turboprop, turbofan, turbopumps, compressors, and advanced engine core technology. We are developing improved analytical and experimental methods for avoiding flutter and minimizing forced vibration response of aerospace systems. In dynamic systems response and analysis, we are analyzing and verifying the dynamics of interacting systems as well as developing concepts and me thods for controlling motion in space and microgravity environments. We are developing advan ced computer programs for analyzing, predicting and controlling the stability and dynamic response of aerospace propulsion and power system components such as rotating bladed structural assemblies, engine rotors, high-speed shafting, and the coupled interactions of blade-disk-shaft-casting structural systems.

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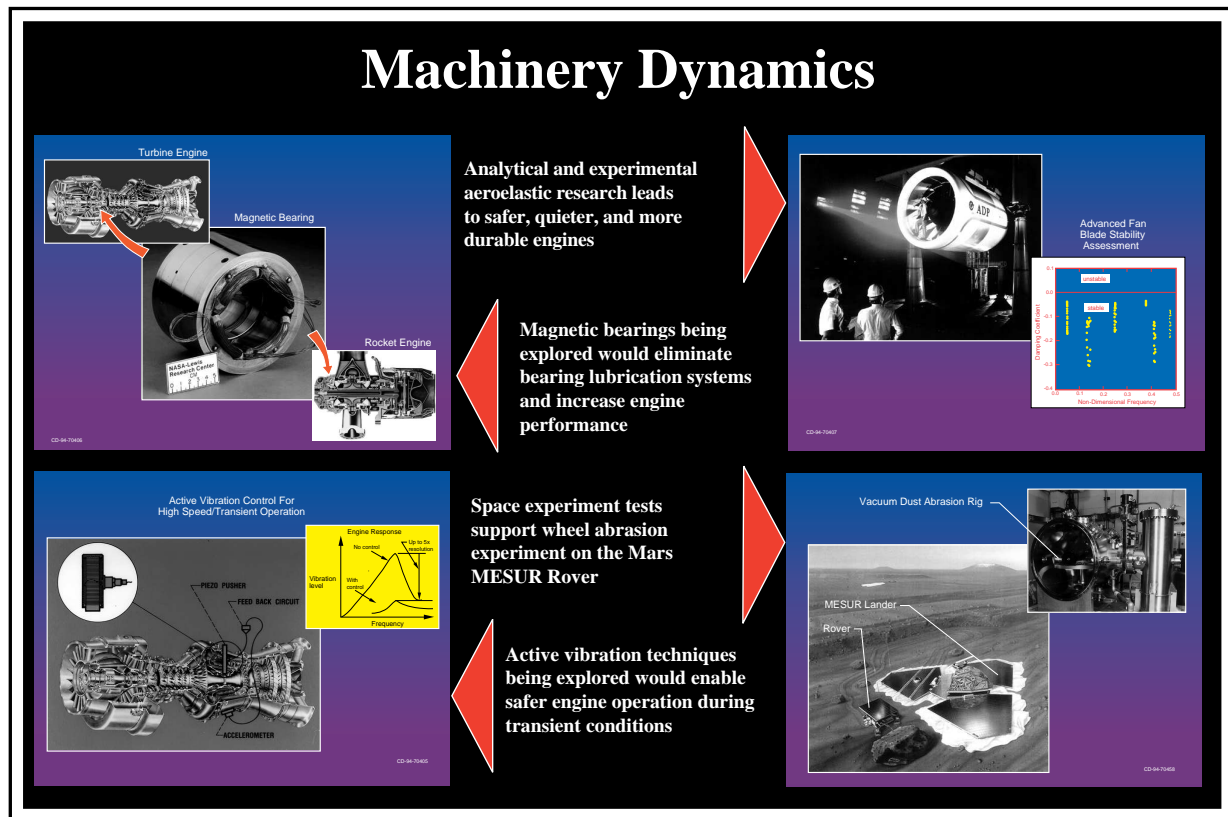
MAGNETIC SUSPENSION SYSTEMS

Research is being conducted to study the feasibility of magnetic suspension system or magnetic bearings for both high temperature and cryogenic ap plications. The application of magnetic bearings to aircraft and rocket engines could impro ve the efficiency of these systems by increasing the rotor speed and controlling the rotor vibr ations. It can also improve the reliability by using magnetic bearings as a health monitorin g device. A magnetic bearing is similar to an electric motor. The magnetic bearing has a la minated rotor and stator made out of cobalt steel. The stator has a series of coils of wire wound around it. These coils form a series of electric magnets around the circumference. These magnets exert a force on the rotor and coupled with displacement probes keeps the rotor in the center of the cavity.
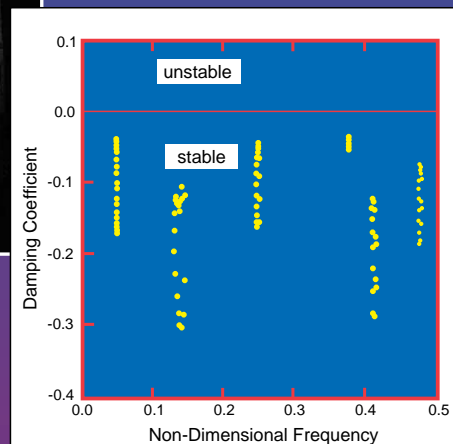

Turbine Engine

Magnetic Bearing

Rocket Engine

NASA-Lewis Research Center
CM
0 1 2 3 4 5

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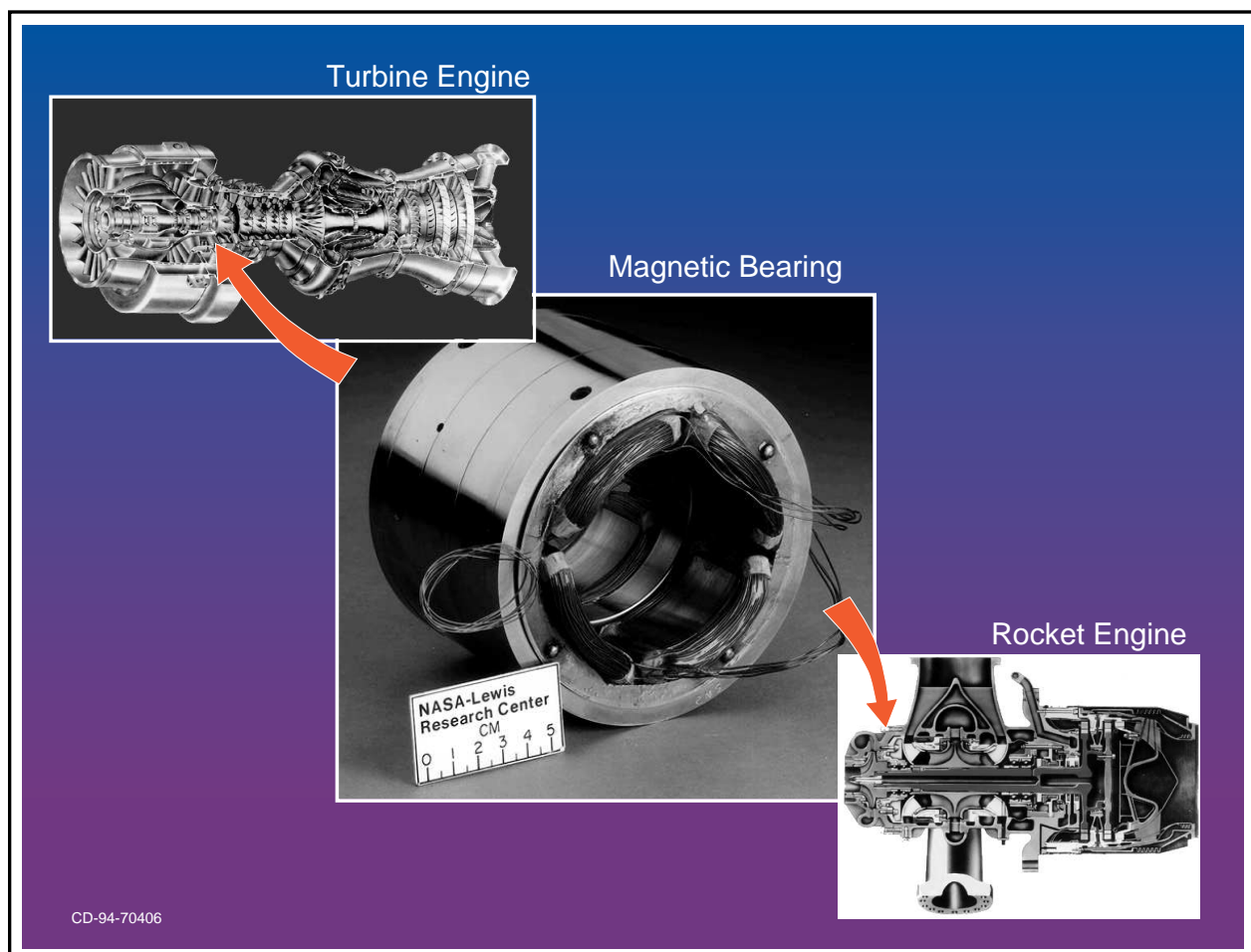
ENGINE DYNAMIC ANALYSIS

Analysis and model testing are being conducted as part of a program to develop low noise advanced wide chord and engines in cooperation with the majo r U.S. engine manufacturers. A demonstrator advanced wide chord fan engine from Pratt & Wh itney is shown in the larger frame. The engine is in the Ames 40-by-80 wind tunnel. An a nalysis was performed by the Structures and Acoustics Division to assess the dynamic stability of a wind tunnel model fan that will be tested at Lewis this year.


Advanced Fan Blade Stability Assessment

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ACTIVE VIBRATION CONTROL

Our research in vibration control includes developing real-time, actively controlled bearing support systems for advanced aircraft turbine engines. Such support systems will reduce advanced aircraft turbine engine weight and rotor vibrations, improve efficiency, and possibly increase stall margins. Expert system controllers are being studied that use advanced computer architectures to adaptively change flight conditions and to monitor the health of the support systems. Gas turbine engine seal efficiency is affected by rotor vibrations which causes the seals to open. Our research is conducted in order to develop a system which senses the vibrations and applies a correction force at the support bearing to cancel them.

Active Vibration Control For High Speed/Transient Operation
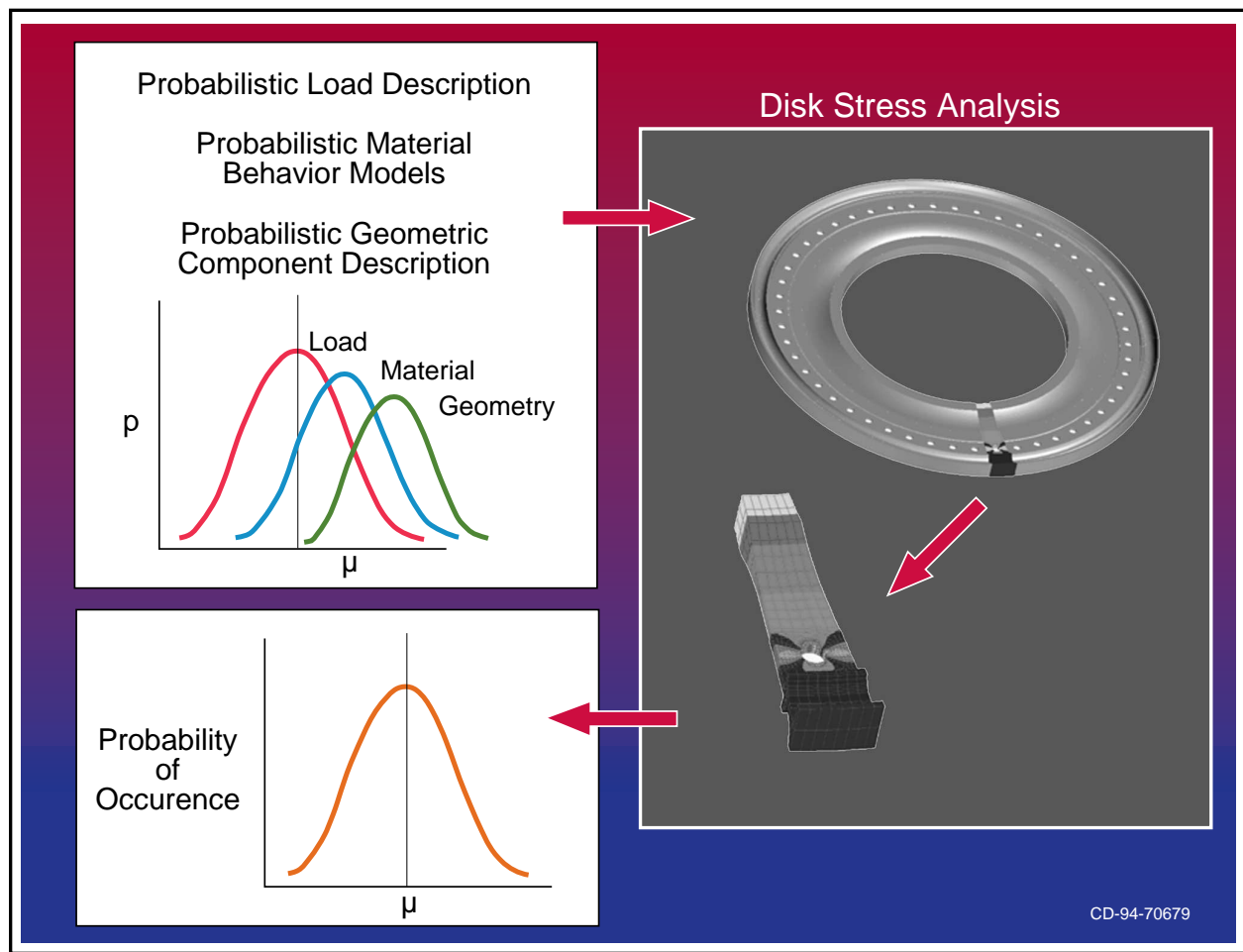
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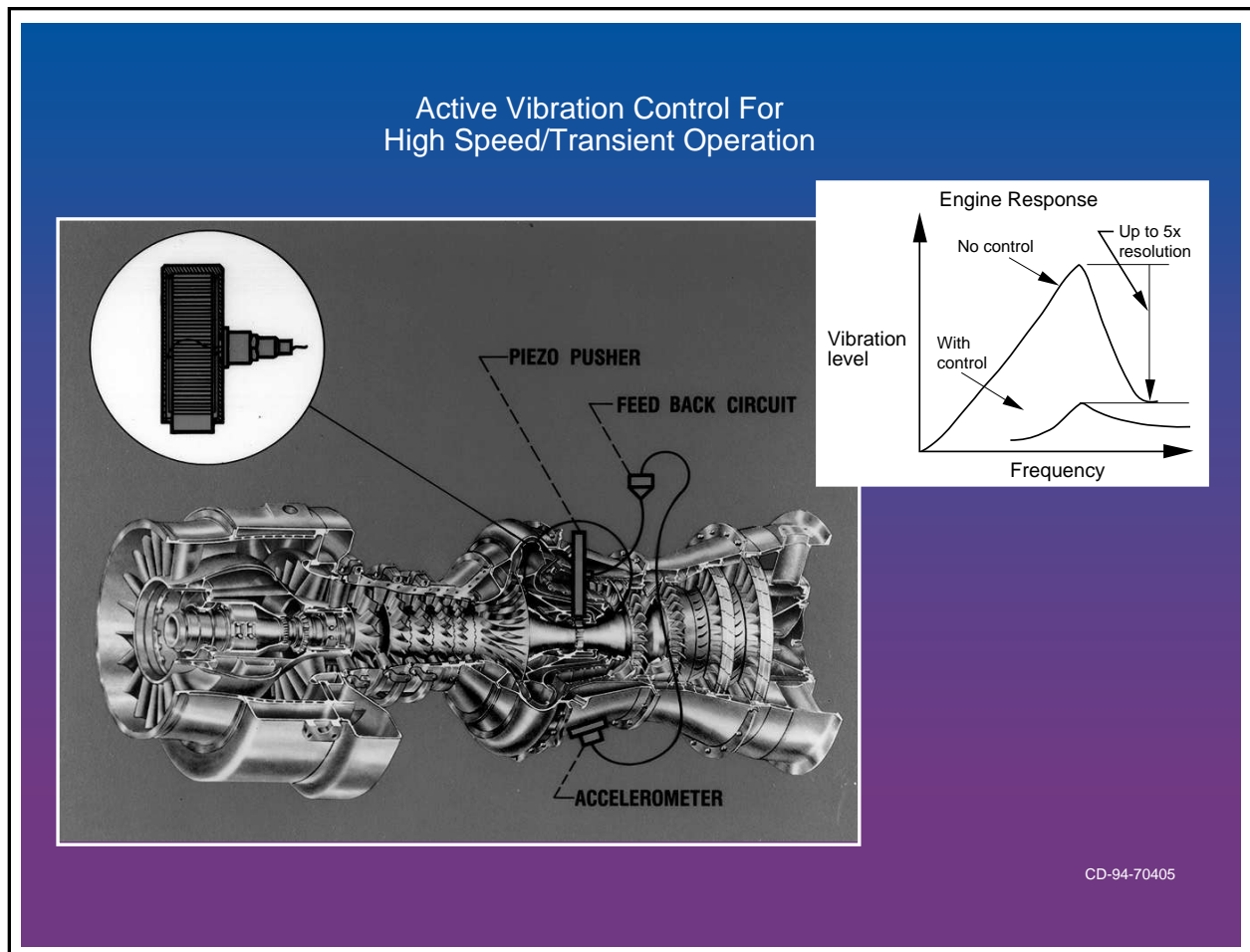
COMPUTATIONAL METHODS

In computational structural methods, we are developing advanced programs for analyzing, predicting and controlling the stability and dynamic response of aerospace propulsion and power system components such as rotating bladed structural assembl ies, engine rotors, high-speed shafting, and the coupled interactions of blade-disk-shaft-casing structural systems. In particular, we are developing and employing computational methods to ana lyze the complex interacting dynamic of advanced turbo-machinery and engine components su ch a fans, compressors, turbines and turbopumps. Analytical methods include both deterministic as well as probabilistic methods. Modeling includes new materials such as metal matrix composites and ceramic matrix composites.


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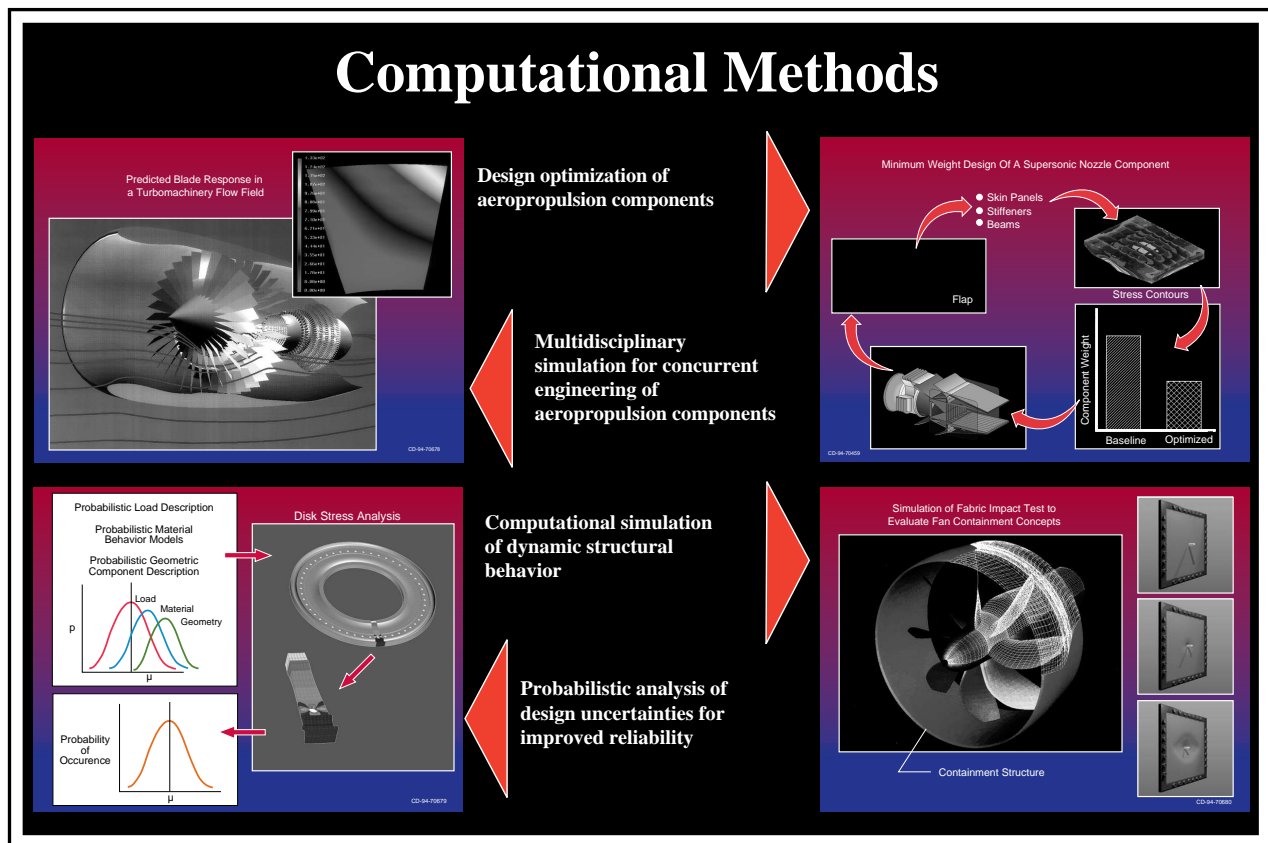
PROBABILISTIC DESIGN FOR STRUCTURAL RELIABILITY AND RISK

Deterministic structural analysis methods are not alway s sufficient to evaluate critical structural components properly for life-rated structural systems. Analysis of aerospace structures are formulated based on: (1) loading conditions; (2) materi al behavior; (3) geometric configuration; and (4) supports. These four fundamental aspe cts are uncertain in nature. One formal way to account for these uncertainties is to develop probabilistic structural analysis methods where the uncertainties in all participating variabl es are described by appropriate probabilistic functions. The objective of this research is t o develop a methodology for computational simulation of uncertainties applied to speci fi c aerospace components. We also exercise the methodology whereby it can be credibly applied to actual product design practice to quantify risk and reliability in life-rated structures.

Probabilistic Load Description

Probabilistic Material Behavior Models

Probabilistic Geometric Component Description

Load
Material
Geometry

p

μ

Disk Stress Analysis

Probability of Occurence

μ

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CONTAINMENT STRUCTURES

In addition to the ballistic impact research program previously described, analytical work is proceeding which uses the results of the experimental program to evaluate fan containment concepts. The LS-DYNA-3D explicit finite element analysis code is used to predict deformation and damage of full-scale containment concepts.

Simulation of Fabric Impact Test to Evaluate Fan Containment Concepts

Containment Structure

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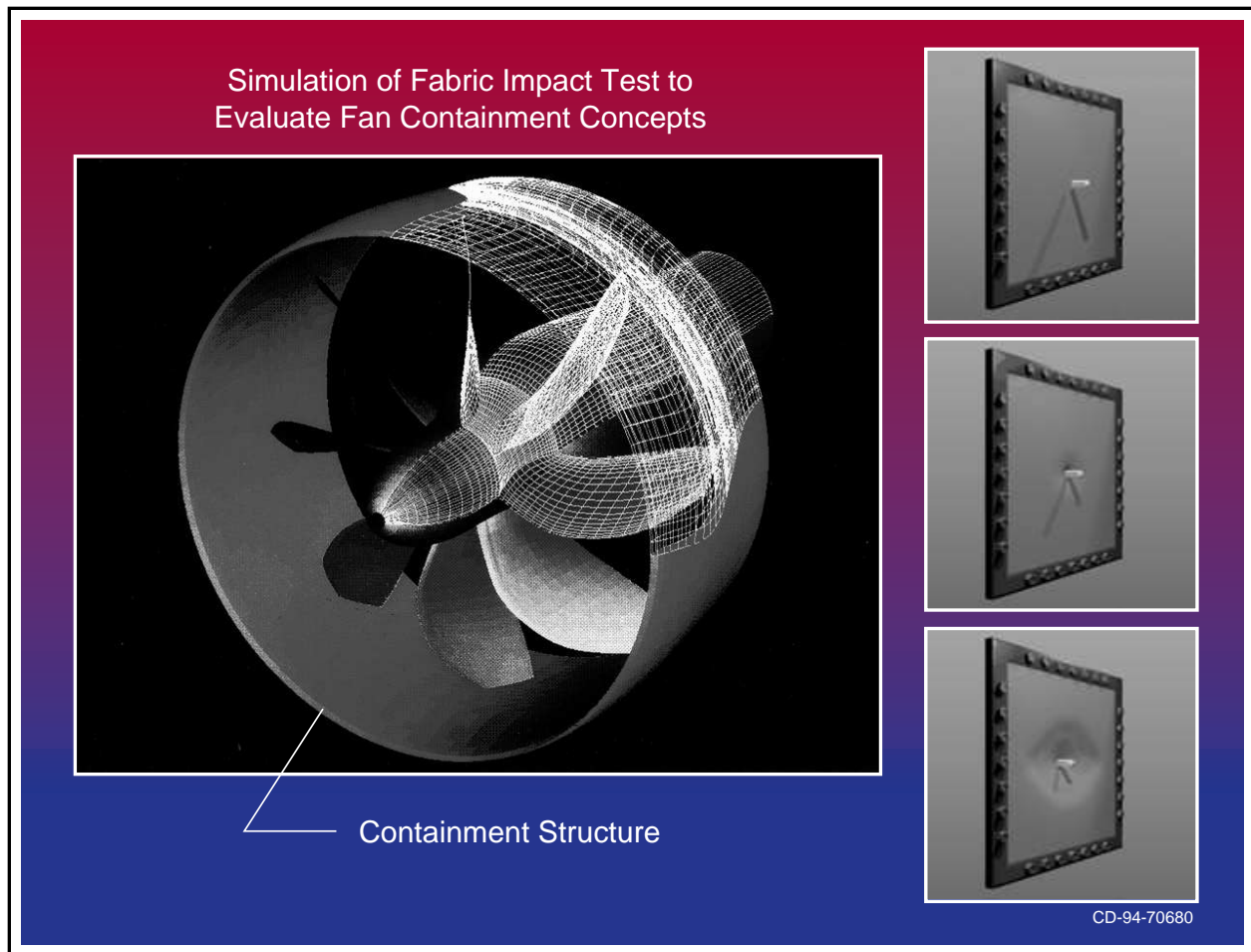
DYNAMIC SYSTEM RESPONSE

We are analyzing and verifying the dynamics of interacting systems. This is illustrated in the figure where compressor and turbine blade responses are predicted in a computer simulation of a full-scale turbine engine. Analyses of this type can be used to optimize engine designs and operation thereby eliminating trial and error experimental methods.

Predicted Blade Response in a Turbomachinery Flow Field

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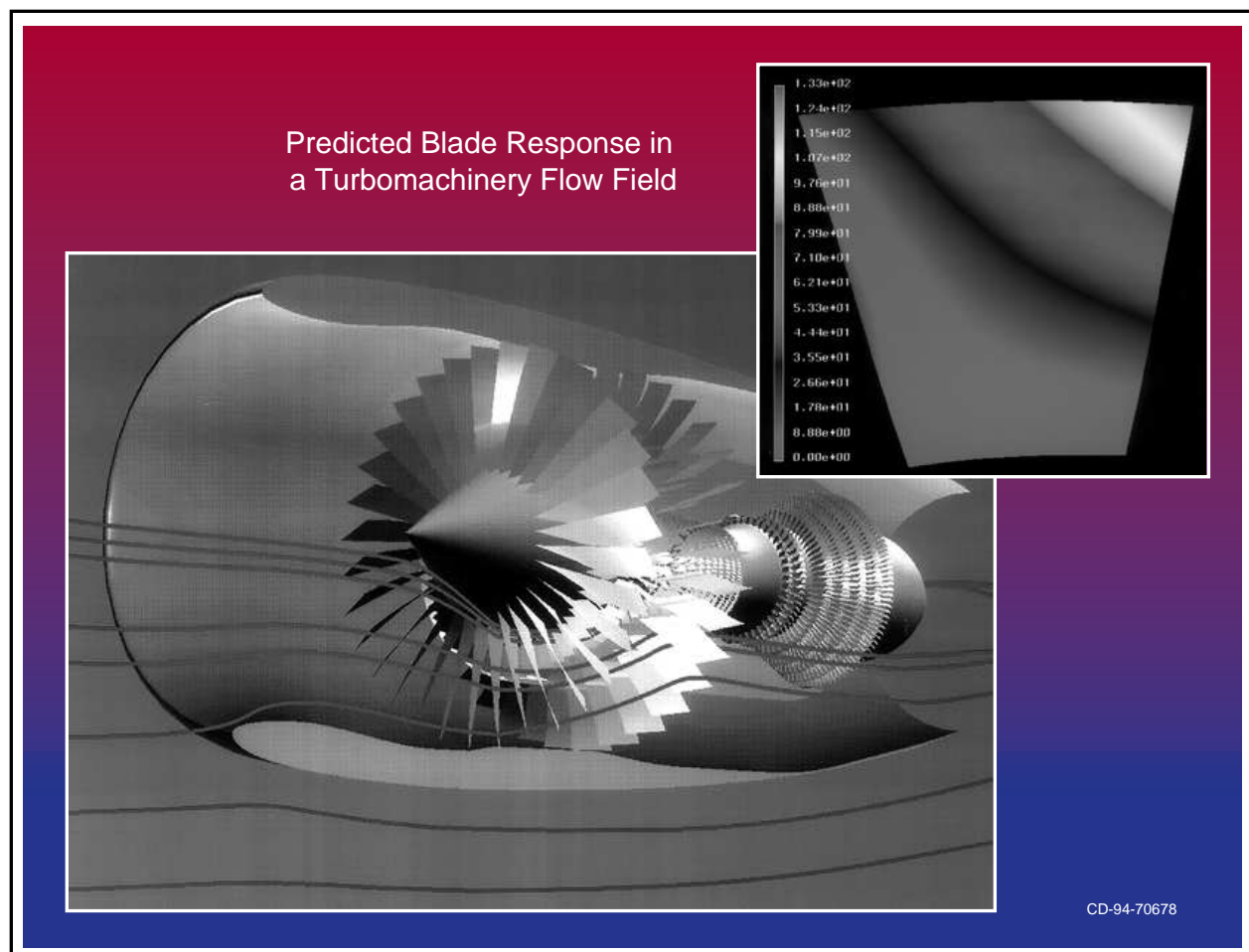
DESIGN OPTIMIZATION

Various computer codes developed by us, or for NASA, are used for design optimization. An example of such aerospace component optimization is illustra ted for a mixed flow turbofan engine exhaust nozzle system for the High-Speed Civil Transport. The nozzle is fabricated out of several components such as rear and forward divergent flaps, rear and forward sidewalls, bulkheads, duct extensions, about six disk supports, etc. De sign complexity of the nozzle increases with flight mach number, pressure ratios, temperature gradients, dynamic response, and degradation of material properties at elevated temperatures. Design optimization of a rear divergent flap of the downstream mixing nozzle was attempted through the design code CometBoards (an acronym for comparative evaluation test bed of optimization and analysis routines for the design of structures). The static as well as dynamic analyses for the flap were carried out utilizing two analysis codes (LEHOST and MSC/N ASTRAN). A qualitative behavior of the flap was explored through its dynamic animat ion. Scrutiny of the animation revealed that skin panel, stiffeners, tapered sidewall and edge beams can be potential candidates for the purpose of design optimization of the flap. The flap was optimized for minimum weight condition for static and dynamic constraints for the potential design variables.

Minimum Weight Design Of A Supersonic Nozzle Component
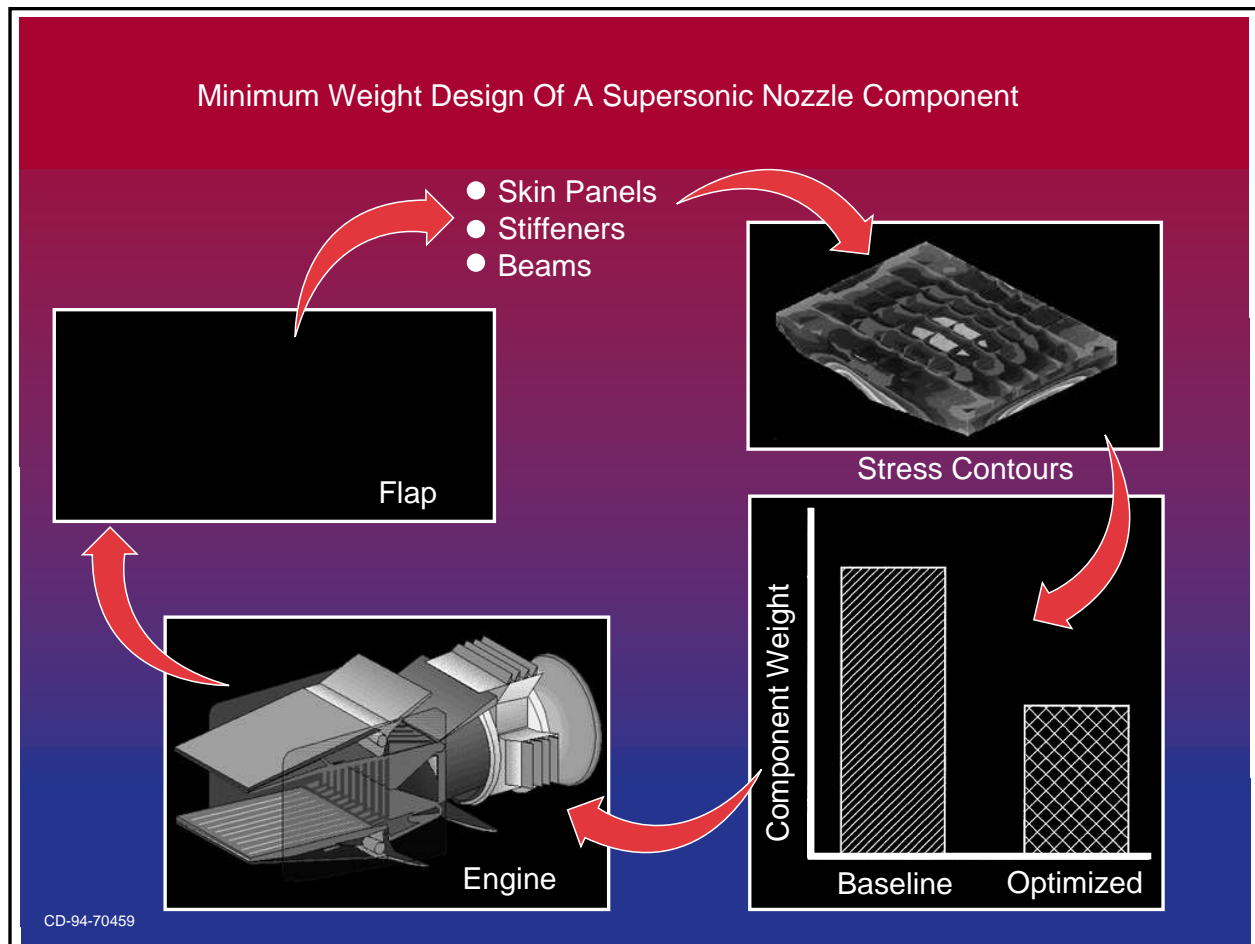
LIFE PREDICTION

The development of verified and validated life prediction models for components experiencing extreme thermomechanical loading conditions such as rocket engine nozzles presents a major challenge. Research is coordinated in a number of technical areas. One such activity is the development of unified viscoplastic constitutive models which are capable of treating plasticity, creep and their interactions. Another area of research is the development of fatigue, fracture and reliability models which are tailored specifically for a particular class of materials.

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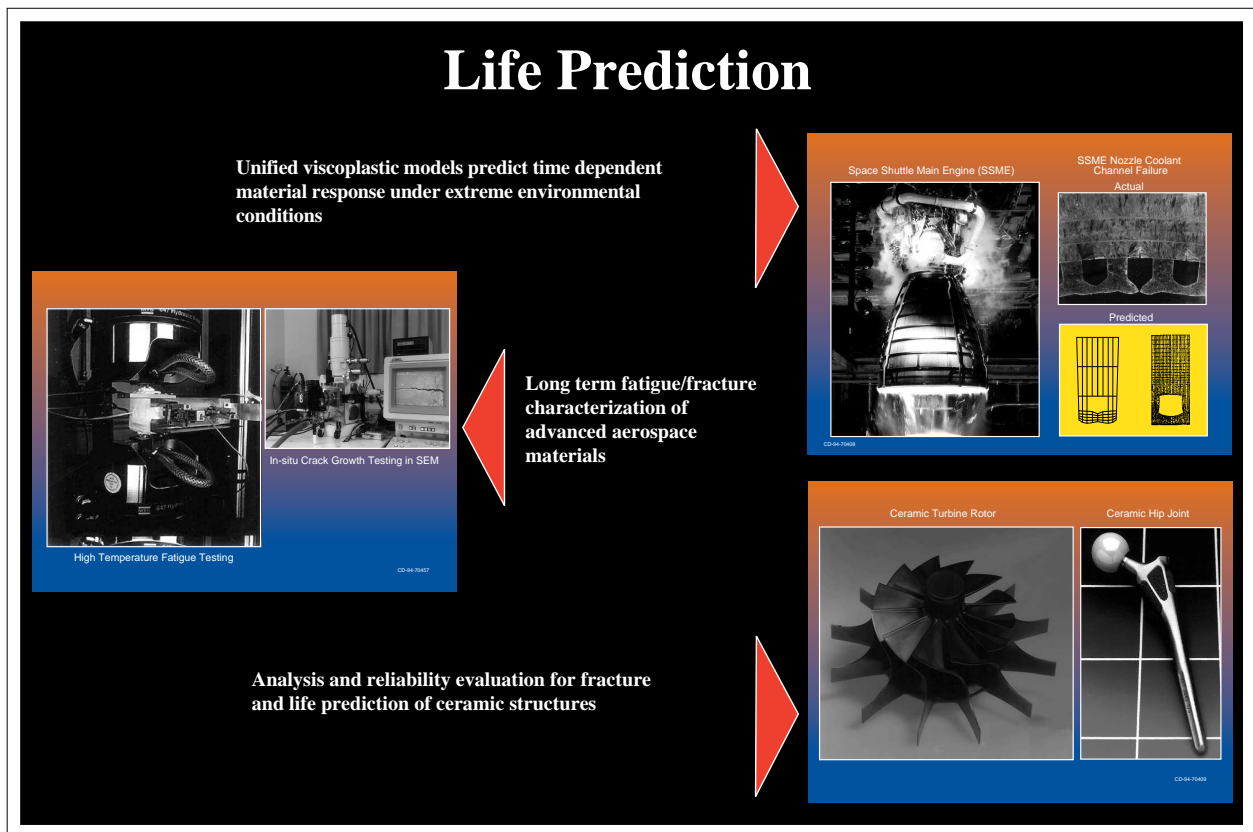
SPACE SHUTTLE MAIN ENGINE (SSME)

The viscoplastic constitutive models we developed and applied to the nozzle coolant channel of the SSME was successful in predicting the failure of the channel under launch conditions and provide a correction to eliminate the failure mode. These mo dels have been successful in predicting the "large" strains which can accumulate at critical locations in actua lly cooled structures as a result of creep ratchetting.
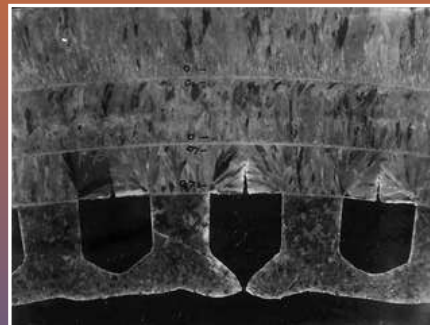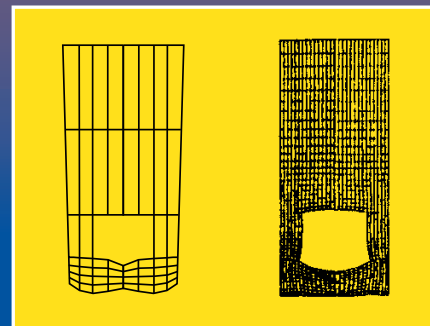
CERAMIC COMPONENTS ANALYSIS

A Structures and Acoustics Division developed code, CAR ES/*Life* (**C**eramic **A**nalysis and **R**eliability **E**valuation of **S**tructures *Life* prediction) is an integrated package that predicts the probability of a monolithic ceramic component's failure as a function of time in service. It couples commercial finite element programs, which resolve a component's temperature and stress distribution, to reliability evaluation and fracture mechanics routines for modeling strength-limiting defects. These routines are based on calculations of the probabilistic nature of the brittle material's strength. CARES/*Life* is used world-wide. Success stories can be cited in several industrial sectors including aerospace, automotive, biomedical, electronic, glass, nuclear and conventional power generation industries.


Ceramic Turbine Rotor
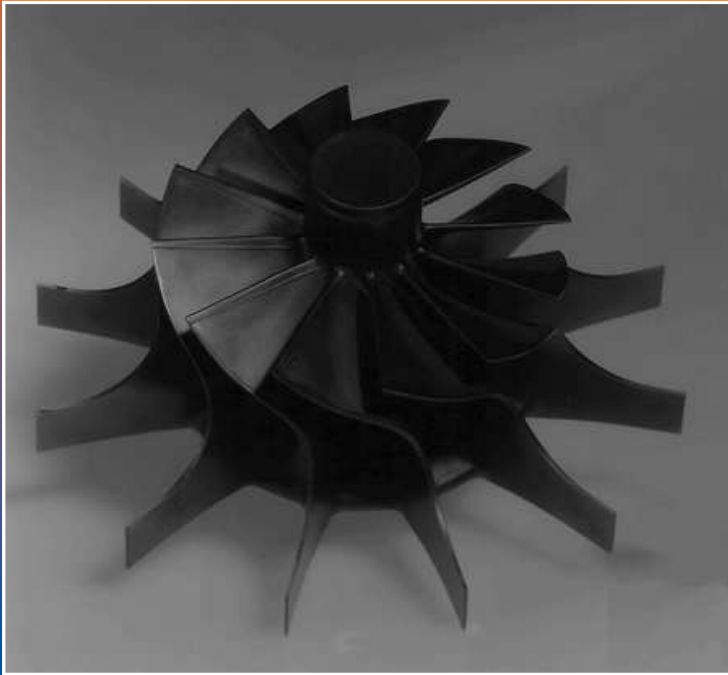
Ceramic Hip Joint

CD-94-70409

BENCHMARK STRUCTURES FACILITY

For many advanced materials considered for aerospace application, the results from coupon testing can be significantly different from that at the component level. A benchmark structures test facility has been developed to address scale-up issues by testing material at the sub-element level. This facility can be used to verify and validate structural analysis methods by generating experimental data under prototypical loading conditions including complex stress states. The results are compared to those predicted by structural analysis.
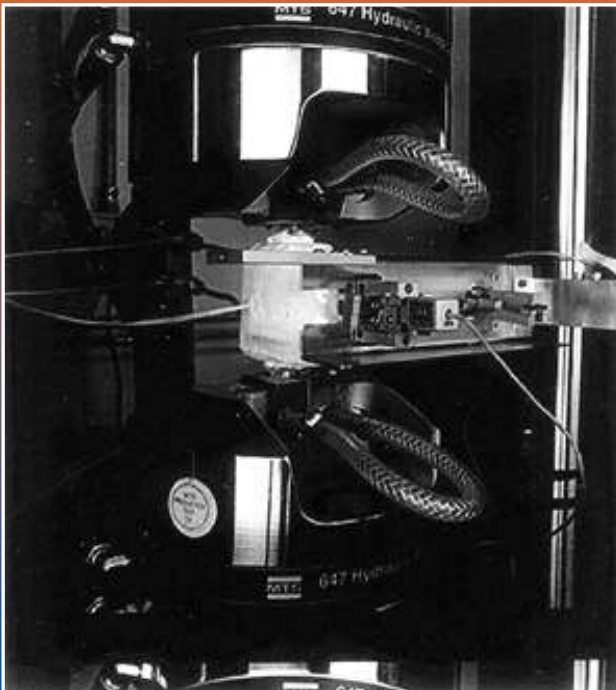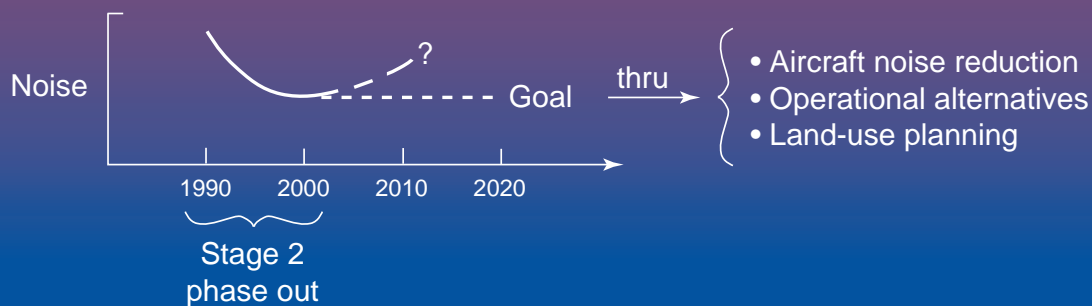

High Temperature Fatigue Testing
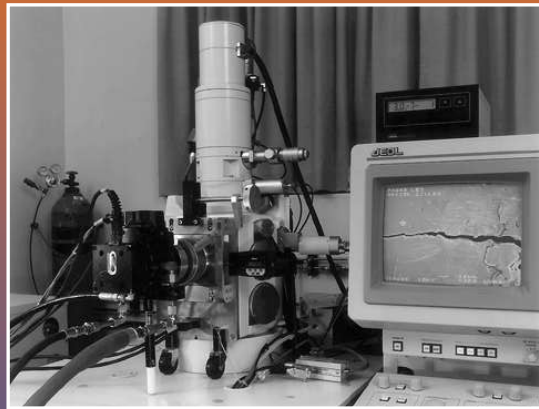
In-situ Crack Growth Testing in SEM

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ENGINE NOISE REDUCTION

The AST Noise Reduction Program started in 1994 to prov ide technology for reducing subsonic aircraft noise 10 dB relative to 1992 technology. E ven though Stage 2 aircraft will be phased out by the end of the decade, increases in the number of flights will cause the noise impact to increase if there is no new technology available. The goal of the AST Noise Reduction Program is to keep the impact of aircraft noise constant aft er all Stage 2 aircraft are phased out. This will be done through the combination of source reductio n for the airplanes (engine and airframe), identifying alternate operations for aircraft, and land-use planning for airports. Lewis is leading the effort to reduce the engine noise by 6 dB as a part of the total 10 dB goal.

NASA/FAA
Subsonic Noise Reduction Technology Program

• Reduce aircraft engine noise and provide for engine growth....

• Ensure no increase in aircraft engine noise into 21st Century

Noise

?

Goal

thru

• Aircraft noise reduction
• Operational alternatives
• Land-use planning

1990   2000   2010   2020

Stage 2
phase out

CD-97-74691

HIGH-BYPASS ADVANCED ENGINE FANS

The major U.S. engine manufacturers, General Electric, Pratt & Whitney, Allison and Allied Signal, bring their advanced design fans to NASA Lewis for t esting. As part of joint programs between NASA and the engine companies, fan models are tested in the 9-by-15 wind tunnel to determine their performance, acoustic and structural charact eristics. The picture shows a NASA/GE model being tested. The microphones used to collect acoustic data are seen against the tunnel wall. Results from experiments have indicated that significant noise reductions can be achieved across the normal fan operating range with modifica tion of the stator vane geometry. Further experimentation will be conducted later in the program to verify the effects of stator vane geometry on fan tone noise at different fan pressure ratios. These encouraging results have stimulated industry into addressing how these new types of s tator vane technologies could be incorporated into the next generation of high bypass turbofan engines.

C-94-01827

MECHANICAL COMPONENTS

Life and failure prediction of drive train components such as rolling-element bearings, gears, clutches and seals is an integral part of the research perfo rmed by the Structures and Acoustics Division. Most of this research is directed towards helicopter transmission systems. The work is both experimental and analytical. Unique test facilities include spiral level gear endurance testers and spur gear endurance testers.
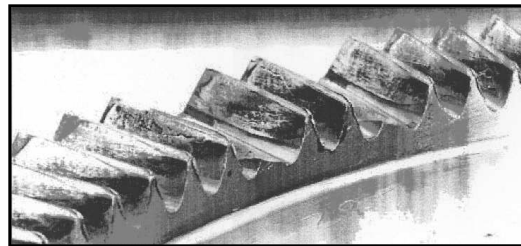
Health and Usage Monitoring and Fatigue and Crack Propagation
Health and usage monitoring and fatigue and crack propagation research to improve safety and reduce maintenance of rotating machinery
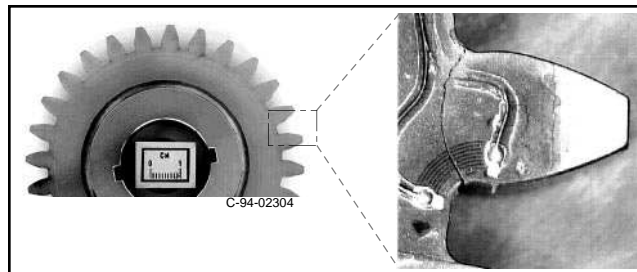
Spiral bevel gear fatigue testing

Gear tooth damage detection

Gear crack propagation and life

C-94-02304

CD-97-74583

ENGINE SEALS

As engine designers are faced with continued challenges to increase aircraft engine performance, reduce engine specific fuel consumption (SFC), and increase engine "time on the wing," they must exploit improvements in many components, including engine seals. With the advent of new concepts such as brush seals, large improvements in engine performance (greater than three-quarters of one percent reduction in SFC) are now being realized. The relatively small investment required to mature these new seal technologies, coupled with appreciable gains in engine performance, makes seal technology development a high technical return on investment.

Seals
Durable low-leakage seals to meet the damands of next generation turbomachinery
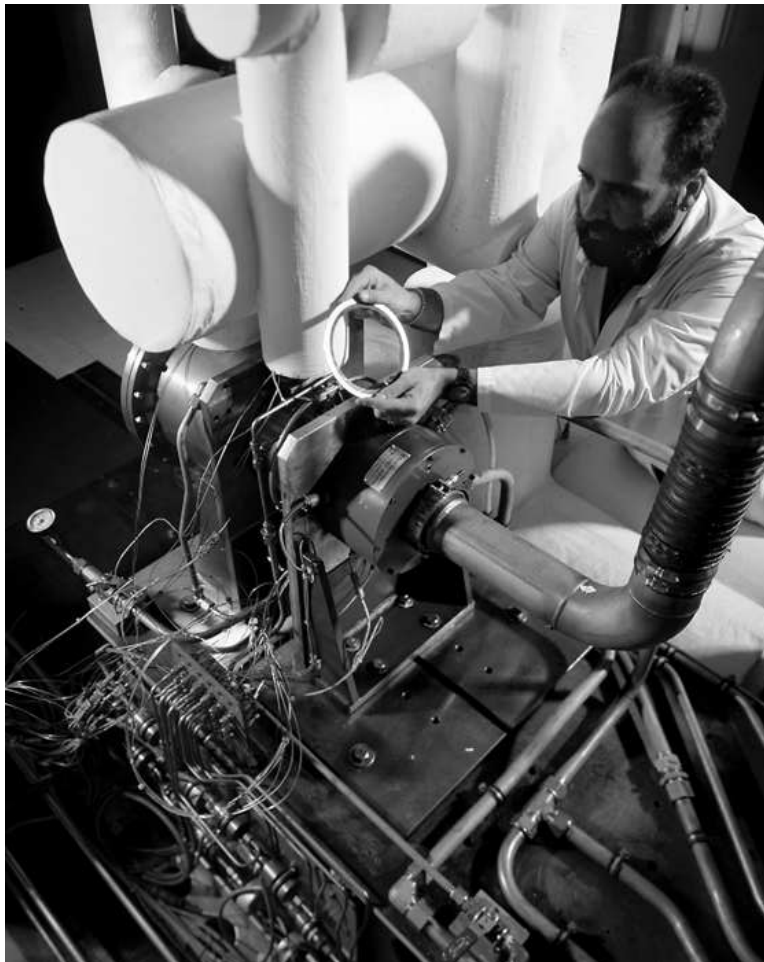
Seals testing

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HELICOPTER DRIVE TRAINS

If the criteria used to design terrestrial gear boxes w ere applied to helicopter and turboprop power transmission systems, these aircraft would be too heav y to carry any significant payload. In addition, as the applied load is increased for a given si ze box, the life and reliability of the transmission decreases by cubic power of load. In order to i mprove the power to weight ratio of these gear boxes as well as to increase their life and relia bility, new design concepts, materials and lubrication concepts are studied and tested by the Struc tures and Acoustics Division. These concepts include high-contact ratio gearing and split-torque designs.

Power Transmission
Power transmission technology synthesized and optimized for improved reliability and safety with reduced weight, noise, and vibration

Face gear split-torque transmission
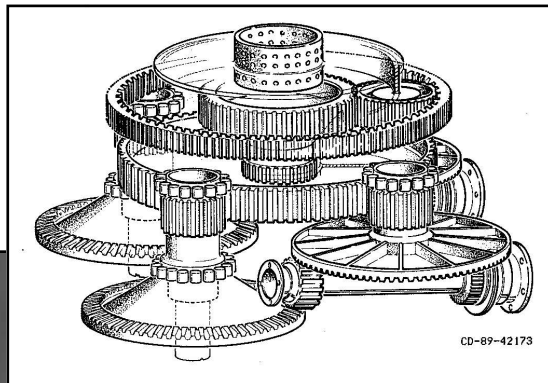
CD-89-42173

Double helical split-path transmission

CD-97-74586

GEARS, BEARINGS AND CLUTCHES

In addition to full-scale transmission research, compon ent work is also performed on an individual scale to develop and verify analytical prediction codes. The essence of this code development and benchmarking is to apply these analytical to ols to optimize mechanical transmission systems to obtain minimum power loss with maxim um life and reliability. Trade-off studies are performed and are verified experimentally. This work has resulted in bevel gears with lower noise and improved performance prediction methods for gear boxes.

Gears, Bearings, and Clutches
Advanced mechanical components realized through use of new materials, concepts, and analytical tools

TEST GEAR

Mechanical diode clutch

Analysis

Experiment

LOAD HISTORY

Experimentally validated analysis methods

Low-noise, high-strength spiral bevel gear
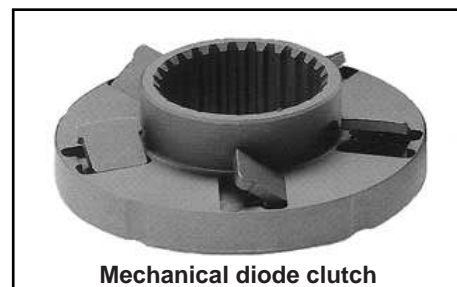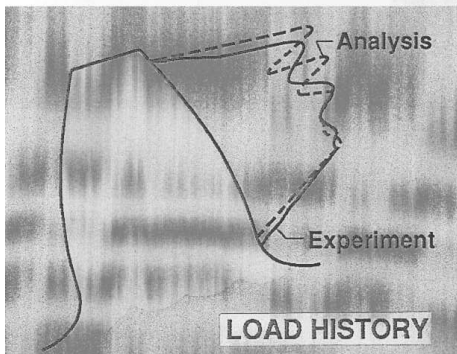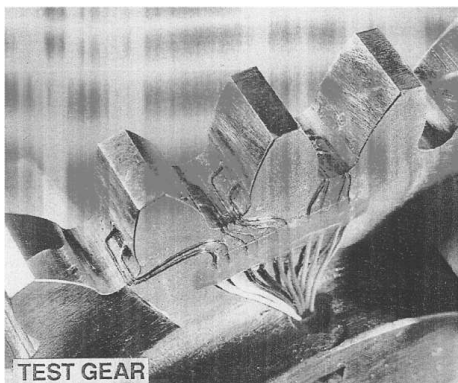
COOPERATIVE PROGRAMS

The Structures and Acoustics Division has been instrume ntal in organizing industry-government consortiums to undertake cooperative pre-competitive technology programs. These programs are organized to consolidate talent and facilities between industry and other government laboratories to accomplish a specific and well de fined goal. The advantage of this effort is gathering a critical mass of talent which does not exist at a single organization to accomplish a single well defined goal. A prime example of this effort is shown in the figure with a combined effort of the named organizations to develop a co mmon life prediction code for metal matrix composite materials.
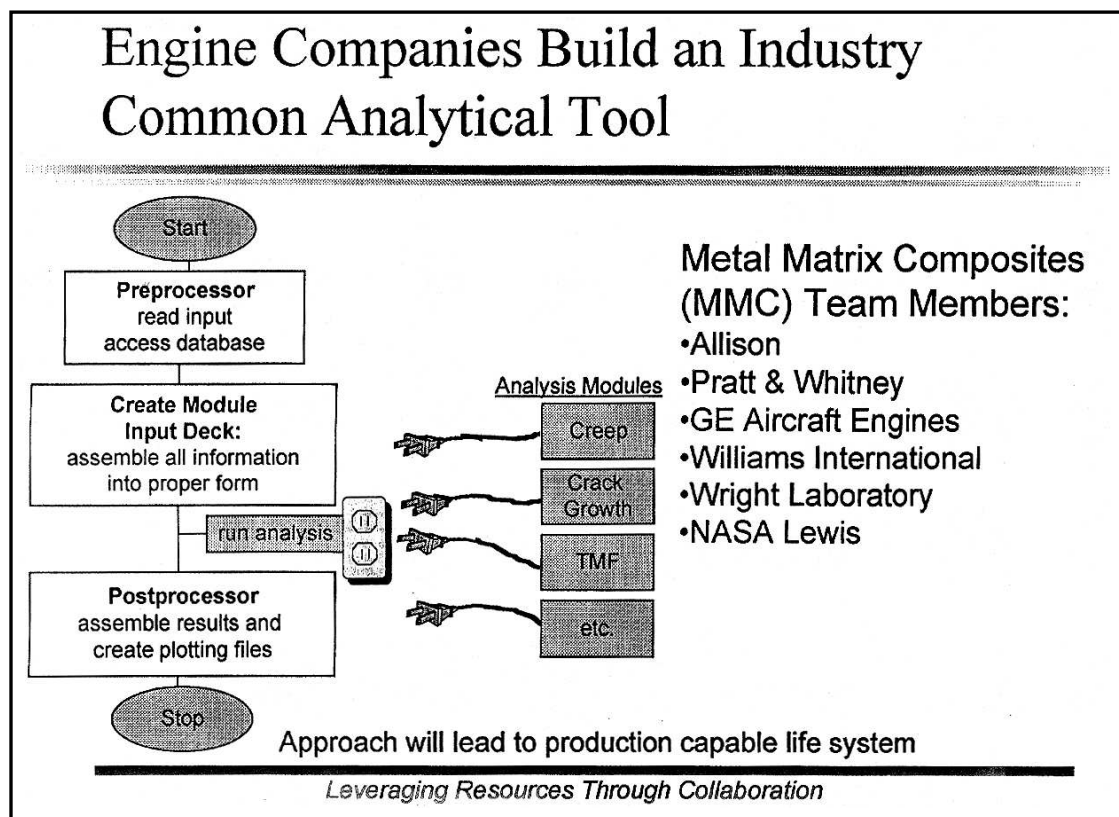
MANAGEMENT STRUCTURE FOR COOPERATIVE PROGRAMS

In order to manage the cooperative programs a virtual company is organized between industry and government participants. The management team is made up of members of participating industry and government organizations. A technical team leader is selected by the management team. The technical team leader together with the technical team manages the day-to-day operation of the program. A program administrator is selected by the management team to act as an administrator facilitator and primary contractor for the work being performed. The program administrator is usually a nonprofit organization. Funding can be from both government and non-government fund sources.

Company-Led Project Team Management Designed to Meet End User Needs

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                    ┌──────────────────┐
                    │ Management Team  │            ┌──────────────────┐
                    └────────┬─────────┘            │  Funding Agency  │
                             │                      └────────┬─────────┘
                             │                               │
                             ├───────────────────────────────┤
                             │                      ┌────────────────────────┐
                             │                      │ Program Administrator  │
                    ┌────────────────────┐          └────────────────────────┘
                    │ Technical Team Leader │
                    └────────┬───────────┘
                             │
    ┌────────────┬───────────┼───────────┬───────────────┐
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│System       │ │Manufacturing│ │User          │ │Independent │ │Commercialization│
│Developers   │ │Process Team │ │Requirements  │ │Review Team │ │Team             │
│Team         │ │             │ │Team          │ │            │ │                 │
└─────────────┘ └────────────┘ └──────────────┘ └────────────┘ └─────────────────┘
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